OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS REVIEW OF THE U.S. DEPARTMENT OF ENERGY KEY TECHNICAL ISSUE AGREEMENT RESPONSES TO CONTAINER LIFE AND SOURCE TERM (CLST).1.14, 2.08, AND 2.09 FOR A POTENTIAL GEOLOGIC REPOSITORY AT YUCCA MOUNTAIN, NEVADA

1.0 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) issue resolution goal during this interim prelicensing period is to ensure the U.S. Department of Energy (DOE) has assembled enough information about a given issue for NRC to accept a license application for review. Resolution by NRC staff during prelicensing does not prevent anyone from raising any issue for NRC consideration during the licensing proceedings. Also, and just as important, resolution of an issue by the NRC staff during prelicensing does not prejudge the NRC staff evaluation of the issue during the licensing review. Issues are resolved by NRC staff during prelicensing when the staff have no further questions or comments about how DOE is addressing an issue. Pertinent new information could raise new questions or comments about a previously resolved issue.

By letter dated December 9, 2003, DOE submitted a report, Technical Basis Document (TBD) No. 6: Waste Package and Drip Shield Corrosion (Bechtel SAIC Company, LLC, 2003a) to satisfy the informational needs of numerous key technical issue (KTI) agreement items. These agreement items pertain to the environmental degradation of the waste package and drip shield materials, and respond to issues raised by NRC related to corrosion processes and the designs of the waste package and drip shield at the potential repository at Yucca Mountain, Nevada. The information was requested by NRC staff during previous technical exchanges in September 2000, February 2001, July 2001, August 2001, and September 2001. Specific agreements addressed in this NRC review of the information provided by DOE in the TBD are Container Life and Source Term (CLST).1.14, 2.08, and 2.09 (Schlueter, 2000).

2.0 AGREEMENTS

The wordings of the agreements are provided next.

CLST.1.14

"Provide the justification for not including the rockfall effect and deadload from drift collapse on SCC [Stress Corrosion Cracking] of the waste package and drip shield. DOE will provide the documentation for the rockfall and dead-weight effects in the next revision of the SCC AMR [Analysis and Model Report] (ANL–EBS–MD–000005) prior to LA [License Application]."

CLST.2.08[1]

"Provide documentation of the path forward items on Slide 16. Rockfall calculations addressing potential embrittlement of the waste package closure weld and rock falls of multiple rock blocks will be included in the next revision of the AMR ANL–UDC–MD–000001, Design Analysis for UCF Waste Packages, to be completed prior to LA. Rock fall calculations addressing drip shield wall thinning due to corrosion, hydrogen embrittlement of titanium, and rock falls of multiple rock blocks will be included in the next revision of the AMR ANL–XCS–ME–000001, Design Analysis for the Ex-Container Components, to be completed prior to LA. Seismic calculations addressing the load of fallen rock on the drip shield will be included in the next revision of the AMR ANL–XCS–ME–000001, Design Analysis for the Ex-Container Components, to be completed prior to LA."

CLST.2.09

"Demonstrate the drip shield and waste package mechanical analysis addressing seismic excitation is consistent with the design basis earthquake covered in the SDS [Structural Deformation and Seismicity] key technical issue [KTI]."

3.0 RELEVANCE TO OVERALL PERFORMANCE

KTI agreements CLST.1.14, 2.08, and 2.09 pertain to the structural response of the engineered barrier system to rockfall and seismic mechanically disruptive events considering material degradation processes. The waste package, composed of the containers and waste forms, is the primary engineered barrier controlling the release of radionuclides from spent nuclear fuel and high-level waste glass. Drip shield performance is important because it is incorporated into the design of the engineered barrier system to limit the amount of water contacting the waste package as a result of seepage into the near-field environment and damage that could occur from rockfall. Initiation of aqueous corrosion of the waste package depends on the deliquescence of dust or contact with seepage water. The presence of the drip shield will delay the contact of seepage water with the waste package surface. Furthermore, structural failure of the drip shield when subjected to accumulated rockfall loads, under either static or seismic conditions, could cause potentially detrimental damage to the waste package. In particular, transferring rockfall loads to the waste package could cause it to experience highly localized plastic stresses and strains in the immediate regions where the drip shield bulkheads mechanically interact with it, although an outright breach of the waste package for this potential scenario is unlikely. Nevertheless, even if the waste package should be breached, the amount of water available for the dissolution of spent nuclear fuel and high-level waste glass and the advective transport of the released radionuclides still could be partially limited by the presence of a damaged drip shield.

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[1]The issues addressed in CLST.2.08 are listed as path forward items in a presentation slide, "Subissue 2: Effects of Phase Instability of Materials and Initial Defects on the Mechanical Failure and Lifetime of the Containers." Future rockfall evaluations will address: (1) effects of potential embrittlement of waste package closure material after stress annealing due to aging; (2) effects of drip shield wall thinning due to corrosion; (3) effects of hydrogen embrittlement on titanium drip shield; and (4) effects of multiple rock blocks falling on waste package and drip shield. Future seismic evaluations will address the effects of static loads from fallen rock on drip shield during seismic events.

The integrity of the drip shield has a medium significance to waste isolation because the drip shield is expected to limit the quantity of water contacting the waste packages and waste forms and also limit the formation of aggressive environments on the waste package surfaces (NRC, 2004). The drip shield also is expected to protect the waste package from accumulated rockfall loads, under both static and seismic conditions. KTI agreement CLST.2.08 is of a high risk significance (Travers, 2003).

4.0 RESULTS OF THE NRC REVIEW

KTI agreements CLST.1.14, 2.08, and 2.09 are included in the integrated subissue for mechanical disruption of engineered barriers. These agreements resulted from a staff review of the DOE documentation that is consistent with Review Methods 2 and 3 in Section 2.2.1.3.2.2 of NRC (2003). The NRC review of the responses for these agreements also was conducted in accordance with these review methods. These review methods include evaluation of the: (i) sufficiency and basis of the engineering data used to support parameters for conceptual and process-level models; (ii) technical bases for parameter values, assumed ranges, probability distributions, and bounding values used in conceptual and process-level models; and (iii) justification of process-level models used to represent mechanically disruptive events within the emplacement drifts. Review Method 3 also requires verification that the effects of mechanically disruptive events on engineered barrier integrity are not underestimated.

4.1 CLST.1.14

Appendix C of TBD No. 6 (Bechtel SAIC Company, LLC, 2003a) presented a summary of the results obtained from structural analyses of the drip shield subjected to accumulated rockfall rubble loads. Table C–1 of this appendix indicates the maximum accumulated rockfall rubble load considered by DOE when assessing the potential for stress corrosion cracking of the drip shield under this condition was consistent with an accumulation of 1.1 m [3.6 ft] of rubble on the drip shield roof. The potential effects of decreasing material thickness caused by general corrosion of the drip shield materials (i.e., Titanium Grades 7 and 24) were accounted for in the analyses by reducing the thickness of the exposed surfaces of the drip shield components by 1.0 and 1.5 mm [0.04 and 0.06 in] (Bechtel SAIC Company, LLC, 2003a, Table C–2). Moreover, as stated in Section C.4, "To assess the potential for SCC [Stress Corrosion Cracking] initiation at various locations, the calculated stresses indicated in Tables C–1 and C–2 are compared with the SCC initiation threshold stresses (50 percent of the at-temperature yield strength) for either room temperature or 150 EC [302 EF]."

Although the effects of potential generalized corrosion appear to have been considered in a conservative manner, the potential accumulated rockfall rubble loads are not consistent with those reported in TBD No. 4 (Bechtel SAIC Company, LLC, 2004a). In addition, there are uncertainties associated with how much rockfall rubble can accumulate on the drip shield and when this accumulation might occur. As a result, the potential range of drip shield accumulated rockfall rubble loads and material temperatures considered in the assessment of stress corrosion cracking should be increased to adequately account for these uncertainties. Furthermore, the calculated stresses presented in Tables C–1 and C–2 (Bechtel SAIC Company, LLC, 2003a, Appendix C) do not appear to be either principal stresses or equivalent uniaxial stress measures (such as Mises or Tresca stresses) that can be used directly to assess the potential for stress corrosion cracking. Lastly, the stress corrosion cracking initiation threshold stresses for the drip shield materials should be consistent with those attained through resolution of KTI agreement CLST.6.01.

Although the staff considers this agreement closed, DOE should consider the following comment:

- The potential rockfall rubble loads used to determine the stresses incurred by the drip shield should be consistent with those documented in TBD No. 4 (Bechtel SAIC Company, LLC, 2004a). The full range of potential drip shield material temperatures should be considered when assessing the potential effects of these alternative rockfall models.

Based on the NRC review of the DOE response to Agreement CLST.1.14 in accordance with methods discussed in the appropriate section of NRC (2003, Section 2.2.1.3.2.2, Review Methods 2 and 3), NRC found the DOE response to the agreement to be satisfactory.

4.2 CLST.2.08

NRC has reviewed the DOE assessment of embrittlement of the waste package closure weld provided in response to Agreements CLST.2.04, 2.05, PRE.7.03, and 7.05. DOE has adequately considered the effects of fabrication processes and thermal instability of the Alloy 22 waste package outer barrier. Based on the information provided by DOE, staff concludes the Alloy 22 waste package outer barrier will still retain ductility that meets or exceeds the ASTM International (1998) minimum elongation standard. Therefore, embrittlement of the waste package does not need to be considered when assessing the response of the waste package to rockfall and seismic mechanically disruptive events.

NRC has reviewed the DOE assessment of titanium corrosion and hydrogen embrittlement provided in responses to Agreements CLST.6.01, 6.02, and 6.03. DOE has adequately addressed corrosion of the drip shield materials and the potential for hydrogen embrittlement. Based on the information provided by DOE, staff concludes the corrosion processes and hydrogen uptake will not significantly degrade the load-carrying capacity of the drip shield.

The DOE response to CLST.2.08 (Bechtel SAIC Company, LLC, 2003a, Appendix K) included a summary of the results obtained from structural analyses of the drip shield subjected to accumulated rockfall rubble and dynamic rock block impact loads. Additional analysis results also were provided for the waste package subjected to dynamic rock block impact loads that could occur during the preclosure period (i.e., before emplacement of the drip shield).

Based on currently available information, the occurrence of rock blocks falling from the roof of the emplacement drift and impacting the drip shield that are of sufficient size to cause appreciable damage only exists in the middle nonlithophysal rock unit. Because this rock unit represents only 15 percent of the potential repository footprint, this postulated mechanically disruptive event is not considered to have an appreciable effect on repository performance (Gute, et al., 2003). Similarly, potential damage that could be incurred by the waste package prior to emplacement of the drip shield during the preclosure period by rock blocks falling from the roof would not be sufficient to breach the Alloy 22 outer barrier (Bechtel SAIC Company, LLC, 2003a, Appendix K).

The finite-element model of the drip shield subjected to accumulated rockfall rubble loads developed by DOE (Bechtel SAIC Company, LLC, 2003b) used shell elements to represent the Titanium Grade 7 plates and solid elements for the Titanium Grade 24 support beams, bulkhead and its flanges, and longitudinal stiffeners. The drip shield materials were modeled as bilinear elastoplastic materials. The mechanical properties used to construct these constitutive models were consistent with publicly available information for the drip shield materials at 150 EC [302 EF].

Based on preliminary confirmatory analyses of the drip shield performed by the staff, several system parameters and modeling assumptions should be considered when evaluating its load carrying characteristics. Specifically, there are uncertainties associated with the estimation of how much rockfall rubble will have to be supported by the drip shield and when this accumulation will occur. The accumulation of rockfall rubble shortly after the cessation of maintenance of the ground support system is likely to increase the temperature of the drip shield, which will lead to reductions in the yield strengths of the titanium alloys. For example, the yield strength for Titanium Grade 7 at 250 EC [482 EF] is reduced by approximately 40 percent relative to the 150 EC [302 EF] basecase (ASME, 2004). Likewise, the yield strength for Titanium Grade 5, which has similar mechanical properties to Titanium Grade 24, at 250 EC [482 EF] is reduced by approximately 17 percent relative to the 150 EC [302 EF] basecase (U.S. Department of Defense, 1998). In addition, the long-term performance of the drip shield may be affected by creep that may occur if stresses in the components are a significant fraction of the at-temperature yield strength (Neuberger, et al., 2002).

The effects of accumulated rockfall rubble should be considered when assessing the response of the drip shield to seismic ground motions. This assessment should consider the variability of the potential ground motions and the uncertainty of the applicable system parameters.

For the proposed drip shield design, three additional concerns are identified by the staff as a result of the preliminary confirmatory analyses. First, separation of the drip shield bulkhead and the support beam by the Titanium Grade 7 plate should be considered. The use of solid elements in finite-element models of the drip shield in this region should represent the effect that localized yielding of the Titanium Grade 7 plate may have on the load-carrying capacity of the drip shield. Second, not accounting for the welds solely transferring tensile loads between drip shield components may underestimate localized stresses. Third, the expected degradation of the invert should be considered in the assessment of the drip shield load-carrying capabilities. Nonuniform settling of the drip shield caused by degradation of the invert (i.e., an unstable foundation) may lead to a decrease in the drip shield load-carrying capacity.

Although the staff considers this agreement closed, DOE should consider the following comments:

- The potential rockfall rubble loads used to determine the stresses incurred by the drip shield should be consistent with those documented in TBD No. 4 (Bechtel SAIC Company, LLC, 2004a). The full range of potential drip shield material temperatures should be considered when assessing the response of the drip shield to accumulated rockfall rubble. In addition, the threshold load-carrying capacity of the drip shield should be provided.

- The potential for low-temperature creep of the drip shield should be considered.

- The effects of accumulated rockfall rubble should be considered when assessing the response of the drip shield to seismic ground motions.

- The expected degradation of the invert should be considered in the assessment of the drip shield load-carrying capacity.

The staff also identified process level modeling assumptions that may affect estimates of the load-carrying characteristics of the drip shield. Specifically, the effects of the following two modeling assumptions should be considered.

- Modeling separation of the drip shield bulkhead and the support beam by the Titanium Grade 7 plate using shell elements.

- Modeling the welds, where appropriate, as the only load path for transferring tensile loads between drip shield components.

Based on the NRC review of the DOE response to Agreement CLST.2.08 in accordance with methods discussed in the appropriate section of NRC (2003, Section 2.2.1.3.2.2, Review Methods 2 and 3), NRC found the DOE response to the agreement to be satisfactory.

4.3 CLST.2.09

The response to KTI Agreement CLST.2.09 (Bechtel SAIC Company, LLC, 2003a, Appendix K) provided a summary of the results obtained from analyses used to approximate the structural responses of the drip shield and waste package to seismic events without considering the presence of rockfall rubble. This information was beyond the scope of agreement CLST.2.09, but was considered in the review of agreement SDS.2.04. The scope of agreement CLST.2.09 was limited to concerns pertaining to the use of seismic ground motions in analyses that either bound, or are consistent with, the design basis ground motions for low probability seismic events attained through resolution of the applicable structural deformation and seismicity KTI agreements. Based on the information presented in TBD No. 14 (Bechtel SAIC Company, LLC, 2004b), however, staff was able to determine the analysis results provided in response to key technical issue Agreement CLST.2.09 were calculated using design basis ground motions that will bound those for low probability seismic events.

Based on the NRC review of the DOE response to Agreement CLST.2.09 (Bechtel SAIC Company, LLC, 2003a, Appendix K) and TBD No. 14 (Bechtel SAIC Company, LLC, 2004b) in accordance with methods discussed in the appropriate section of NRC (2003, Section 2.2.1.3.2.2, Review Method 2), NRC found the DOE response to the agreement to be satisfactory.

5.0 SUMMARY

NRC reviewed the DOE KTI agreement responses within the report to determine whether any important aspects of Agreements CLST.1.14, 2.08, and 2.09 were excluded from the response. In addition, NRC performed confirmatory analyses to determine if the information provided would support submission of a potential license application for a geologic repository. On the basis of this review, NRC has determined that the information provided with respect to

Agreements CLST.1.14, 2.08, and 2.09 and TBD No. 14 (Bechtel SAIC Company, LLC, 2004b) is sufficient to support the submission of the license application.

6.0 STATUS OF THE AGREEMENTS

Based on the preceding review, NRC agrees with DOE that the information provided with respect to Agreements CLST.1.14, 2.08, and 2.09 and supporting information provided in TBD No. 14 (Bechtel SAIC Company, LLC, 2004b) is sufficient to support a license application. Therefore, NRC considers agreements CLST.1.14, 2.08, and 2.09 to be closed.

7.0 REFERENCES

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